A Robotic Indenter for Minimally Invasive Characterization of Soft Tissues

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Outline

- Problem
- Our Approach
- Literature Review
- Design of the Robotic Indenter
- Controller Design & GUI
- Animal Experiments
- Experimental Results
Problem

The lack of data in current literature on \textit{in–vivo} material properties of soft tissues has been a significant impediment in the development of virtual reality based laparoscopic simulators that can provide the user with realistic visual and haptic feedback for training medical personnel.
Goal

*In-vivo* characterization of soft tissue properties for integration into tissue models to be used in VR based surgical simulators.
Soft organ tissues exhibit nonlinear, anisotropic, nonhomogeneous, time, and rate dependent behavior, which are extremely challenging to measure, especially in vivo.
Our Approach

- Development of a robotic indenter
- Design of measurement experiments
- Extraction of tissue properties from measured data
Our Approach

Robotic Indenter

Experiments

Tissue Properties

Collected Data
Literature Review

- **Measurement site**
  - in a living body (*in–vivo*)
  - within a body (*in–situ*)
  - outside the living body (*in–vitro, ex–vivo*)

- **Measurement methods**
  - *invasive*: a part of the body is entered, as by puncture or incision
  - *non–invasive*: the body is not cut open, e.g. ultrasound
  - *minimally invasive*: e.g. laparoscopy
Literature Review

- **Hand-held**
  - *Invasive*
    - Carter et al.
  - *Minimally Invasive*
    - Kauer et al.

- **Robotic**
  - *Invasive*
    - Tay et al.
  - *Minimally Invasive*
    - Ottensmeyer
    - Brown et al.


Our Contribution

- Robotic Probes vs Hand-Held Probes
- Minimally Invasive vs Invasive
- Large indentations vs small indentations
- Static vs Dynamic indentations
Components of the Robotic Indenter

- Phantom haptic device (encoders for 3D position sensing)
- Laparoscopic Probe
- Nano 17 force sensor (3D force/torque sensing)
- Cover
Controller Design

- PID control and tuning

\[
SP(nT) + E(nT) = F(nT) = CV(nT)
\]

Haptic Library
- \(send_forces(F(nT))\)
- \(PV(nT) = get\_position()\)

Sensor Library
- \(RF(nT) = get\_forces()\)

Recording
- \(PV(nT)\)
- \(RF(nT)\)
- \(Time(nT)\)
Graphical User Interface

- Automates the generation and execution of indentation profiles and data collection.

![Graphical User Interface Image]

College of Engineering, Koc University
Preliminary Experiments

Observation in Operating Room
Animal Experiments

In collaboration with Department of Surgery and Faculty of Veterinary Medicine of Istanbul University.
Animal Experiments

- Indentation types
  - Static indentation
  - Stress relaxation
  - Dynamic indentation

![Diagram showing static and dynamic indentation with depth and time axes](image)
Experimental Results

- Effective elastic modulus for small indentation of an elastic half-space by a rigid hemispherical indenter

\[ E = 2G(1+\nu) \]

\[ G = \frac{3P}{16\delta\sqrt{R\delta}} \]

<table>
<thead>
<tr>
<th>Indentation Depth ( \delta ) (mm)</th>
<th>Effective Young's Modulus ( E ) (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>16.9 ± 4.9</td>
</tr>
<tr>
<td>4</td>
<td>12.4 ± 4.1</td>
</tr>
<tr>
<td>6</td>
<td>10.8 ± 4.7</td>
</tr>
<tr>
<td>8</td>
<td>10.0 ± 4.7</td>
</tr>
</tbody>
</table>
Experimental Results

- Prony Series expression

\[ G(t) = G_\infty + \sum_{k=1}^{N} G_k e^{-t/\tau_k} \]

<table>
<thead>
<tr>
<th>Pig #1</th>
<th>Pig #2</th>
<th>Pig #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(G_1) (kPa)</td>
<td>2.402</td>
<td>3.688</td>
</tr>
<tr>
<td>(G_2) (kPa)</td>
<td>1.733</td>
<td>2.495</td>
</tr>
<tr>
<td>(\tau_1) (s)</td>
<td>0.979</td>
<td>1.000</td>
</tr>
<tr>
<td>(\tau_2) (s)</td>
<td>5.650</td>
<td>9.000</td>
</tr>
<tr>
<td>(G_\infty) (kPa)</td>
<td>4.593</td>
<td>3.193</td>
</tr>
</tbody>
</table>
Acknowledgement

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